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DAU AND FCC DOCKET 19311 COMPLIANCE TEST REPORT

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RADC-TM-77-16 has been reviewed and is approved for publication.

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18. SUPPLEMENTARY NOTES

Although documentation of the results contained in the TM was accomplished in-house, the program was carried out with contractual support from Aeronutronic Ford Corporation, 3900 Welsh Road, Willow Grove PA 19090.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Microwave Digital Data Transmission
Spectral Occupancy
Digital Modems
Telecommunications

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Digital Applique Unit (DAU) is a device designed to permit the efficient conveyance of digital data and digital service channel signals over conventional FM microwave radio sets. FCC Docket 19311 is a new digital data spectral emission standard issued by the Federal Communications Commission. This technical memorandum contains the results of a program conducted to assess the impact on the DAU of enforcing full adherence to the digital emission provisions of FCC Docket 19311.

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1.0 Background

1.1 Introduction

Until 1974 microwave frequency allocations were authorized based upon 99 percent bandwidths. With the advent of digital microwave and the potential for increased congestion and interference, a new standard termed "Docket 19311" was issued by the Federal Communications Commission (FCC). This more restrictive standard has been accepted by the military for use in the United Stated and there are indications that it may eventually be required in the Defense Communications System (DCS) worldwide.

The Digital Applique Unit (DAU) is a device designed to permit the efficient conveyance of digital data and digital service channel signals over conventional FM microwave radio sets such as the Aeronutronic Ford LCT Series of microwave radios. Reference 1 contains a detailed description of the DAU, its operation and operational characteristics. The DAU spectral occupancy requirements having been initiated prior tc the 19311 Docket were defined in a 99 percent RF bandwidth. The experimental test program reported upon herein was conducted to ascertain the changes necessary to enable the DAU to meet the more restrictive 19311 spectral occupancy requirement.

1.2 DAU Rates and Bandwidths

The DAU synchronously time division multiplexes a single 192K bps service channel with one or two mission bit streams of rate 3.168, 6.336, 9.504 or 12.672 Mbps. The resulting modem rates are 3.456, 6.912, 10.368, 13.824, 20.736 or 27.648 Mbps. A 20 stage randomizer is provided between

the multiplexer and the 4 level amplitude modem to minimize the generation of discrete frequency components in the output power spectrum.

LOS microwave allocations for the U. S. in foreign countries are in the 4.4 to 5.0 and 7.1 to 8.4 GHz bands. Bandwidths allocated are in multiples of 3.5 MHz. By authorizing contiguous bands allocations of 3.5, 7.0, 10.5 or 14 MHz are granted. 14 MHz is the widest bandwidth authorization granted.

Table 1 lists the modem rate/bandwidth allocation combinations anticipated in future applications of the DAU.

Modem Rate (Mbps)	Bandwidth I (MHz)	Bandwidth II (MHz)
3.456	3.5*	Not Applicable
6.912	7.0	3.5*
10.368	10.5	7.0
13.824	14.0	7.0
20.736	Not Applicable	10.5
27.648	Not Applicable	14.0

* Applicable to 4 GHz band only.

TABLE 1. MODEM RATE/BANDWIDTH ALLOCATION COMBINATION

1.3 Different Spectral Emission Limitations

There are three different spectral emission requirements pertinent to this report as identified below:

Original DAU Specification: Ninety-nine (99) percent of the transmitted signal energy shall be within the authorized bandwidth. The mean power of emissions in any 4 kHz band (3 dB) outside the authorized bandwidth shall be attenuated below the mean transmitter output power as follows:

a. On any frequency removed from the center frequency by more than 50 percent, up to and including 100 percent, of the authorized bandwidth: at least 25 dB.

b. On any frequency removed from the center frequency by more than 100 percent, up to and including 250 percent, of the authorized bandwidth: at least 35 dB.

c. On any frequency removed from the center frequency by more than 250 percent of the authorized bandwidth: at least 80 dB.

Proposed DCA/DCEC Revision: Replace subparagraphs a. through c. in the original specification by:

$$A = \begin{cases} .3P + 20 & 50 \leq P < 100 \\ .5P & 100 \leq P < 150 \\ 75 & P \geq 150 \end{cases}$$

where: A is the attenuation (in dB) below the mean output power

P is the percentage removed the authorized center frequency relative to authorized bandwidth.

FCC Docket 19311 Specification (Digital Modulation): The pertinent portion of this docket as modified in January 1975 requires that the attenuation of the transmitted spectrum in any 4 kHz band (3 dB) relative to the mean transmitter output power shall not be less than that given by the following relationship:

$$A = 35 + .8\ (P - 50) + 10 \log_{10} B$$

where: B = authorized bandwidth in MHz.

These attenuation values shall govern for frequencies removed from the center frequency by more than 50 percent up to and including 250 percent of the authorized bandwidth. Attenuation in these areas shall not be less than 50 dB and attenuation greater than 80 dB is not required.

FCC Docket 19311 limitations for transmission other than those employing digital modulation techniques differ from the original DAU specification only in that c. is replaced by:

c. On any frequency removed from the assigned frequency by more than 250 percent of the authorized bandwidth: at least 43 plus 10 $\log_{10}$ (Mean output power in watts) decibels, or 80 decibels, whichever is the lesser attenuation.

Thus, the original specification can be considered as a worst case specification for FDM/FM systems. It was selected by reasoning that since the links on which the DAU would be used would be replacing analog transmission links the analog requirements should suffice. DCA/DCEC's revision was intended to provide a transmitted bandwidth requirement more stringent than the FCC Docket 19311 FDM/FM requirements without imposing a severe

redesign requirement on the DAU or the associated radios' filters. The revision imposed requirements significantly more restrictive than the original specification but requirements which it was felt the prototype DAU already satisfied. The FCC Docket 19311 Specification (Digital Modulation), which may require satisfaction, is much more restrictive and as will be seen requires radio modifications for satisfaction.

Figure 1 indicates the relative constraints imposed by the three specifications where an authorized bandwidth of 14 MHz is assumed. When plotted on a percentage basis as in Figure 1, the spectral masks for the original specification and the DCEC specification are dependent only upon P and so remain unchanged for different bandwidths. Because of the manner of dependency of the 19311 specification on B, the mask for smaller bandwidth allocations if plotted on Figure 1 would either coincide with or occur outside the 14 MHz mask. In this respect the 14 MHz mask at the 27.648 Mbps modem rate represents the worst case condition and as such is the bandwidth addressed in greatest detail.

2.0 Prior Spectral Occupancy Tests

2.1 Initial Test Program

The DAU spectral occupancy characteristic can be varied by an adjustment of the deviation ratio of the radio set deviator, which can be accomplished by use of a variable attenuator inserted between the modem and radio interface. Under the initial DAU test program (Reference 1) deviation ratios were determined which yielded a 99 percent spectral occupancy characteristic for each modem transmission rate/bandwidth

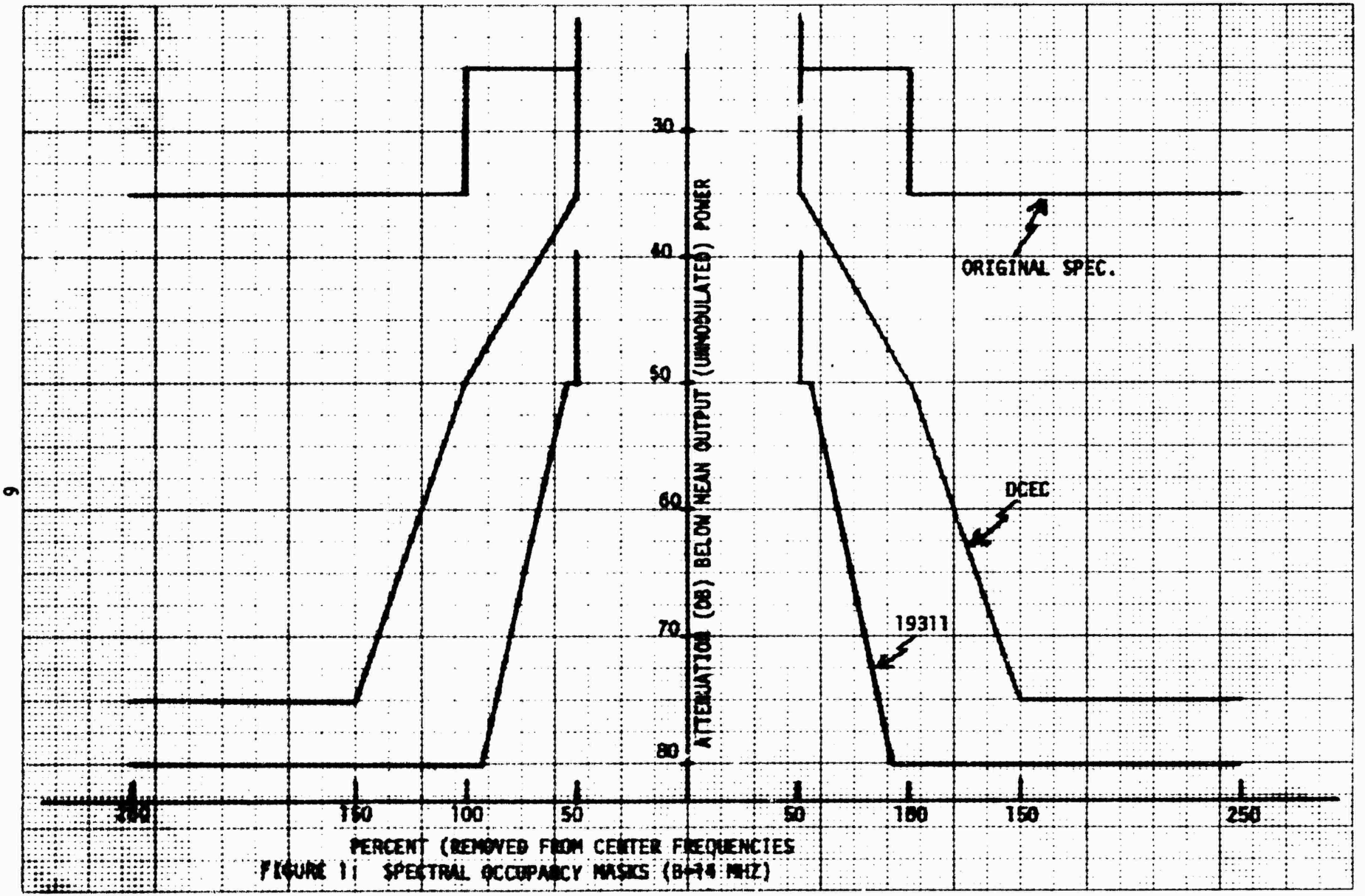

FIGURE 1: SPECTRAL OCCUPANCY MASKS (8-14 MHZ)

combination of interest. The measurement procedure entailed the obtaining of a plot of the RF spectral power density as a function of frequency and the integration of the spectral density by means of a polar planimeter. The RF power plot was obtained using the HP-8555A spectrum analyzer linear detector and an external voltage squaring device to convert the voltage levels to power. Details are contained in Reference 2. Results for the LC-8D Radio Set are given in (1) along with the comment that essentially the same peak-to-peak deviation was required for the LC-4D, LC-4A, AN/FRC-162 and AN/FRC-80. As a result of these measurements and the performance test results given in the same report, it was previously demonstrated that the DAU in conjunction with compatible radio sets yields acceptable performance when the 99 percent spectral occupancy requirement is met.

2.2 DCA/DCEC Revision Test Program

In order to determine compliance of the DAU with the DCEC requirements a subsequent detailed test program was conducted by RADC. Testing in conjunction with the LC-8D was carried out at RADC; testing with the AN/FRC-80 and AN/FRC-162 was carried out at Richards-Gebaur Air Force Base, Missouri. The results are presented in Reference 2. The tests demonstrated a satisfaction of the DCEC proposed spectral mask. Clearly a satisfaction of this mask automatically provides a satisfaction of the original DAU specification mask.

3.0 FCC Docket 19311 Program

3.1 Motivation for the Program

A plotting of the 19311 mask on the spectrums given in References 1 and 2 shows that none of the radios as tested with the DAU meet the docket requirements. The spectral curves for the LC-8D at 13.824 Mbps and 27.648 Mbps within a 14 MHz bandwidth are singled out for demonstrative purposes. Figures 2 and 3, which were obtained from Figures 83 and 89 respectively of Reference 2, illustrate how significantly the DAU fails to satisfy the requirement. The masks on these figures and all subsequent figures have been adjusted upward by 2.3 dB to normalize the IF bandwidth to a 4 kHz bandwidth and to correct for detector characteristics and log shaping which tend to amplify noise peaks less than the rest of the signal (Reference 3). At the +14 MHz offset, it fails by approximately 17 dB at the 27.648 Mbps modem rate and about 5 dB at the lower rate. Because of these results and the possibility that the DAU may be required to meet the 19311 specifications, a program was conducted to assess the impact of enforcing full adherence to the digital emission provisions of the FCC docket.

3.2 Approach

A contract was awarded to Aeronutronic Ford Corporation to provide modifications to the LC-8D radio set to permit the emission characteristics of the radio, when interfaced with the DAU, to meet the FCC 19311 authorized bandwidth specifications. The primary program objective was the maximization of the DAU error rate performance while achieving an LC-8D transmitter emission characteristic that is in compliance with the

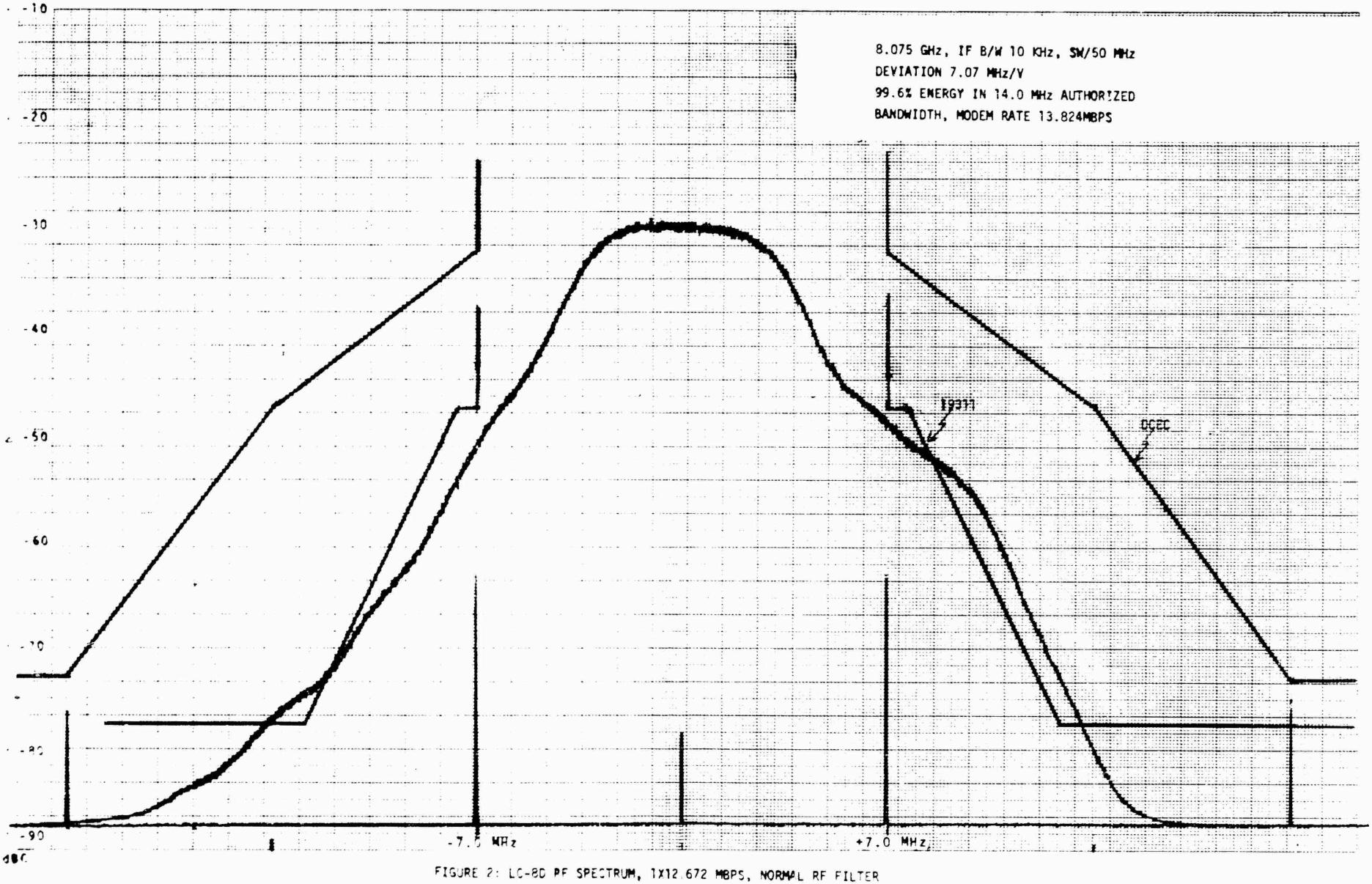

FIGURE 2: LC-8D RF SPECTRUM, 1X12.672 MBPS, NORMAL RF FILTER

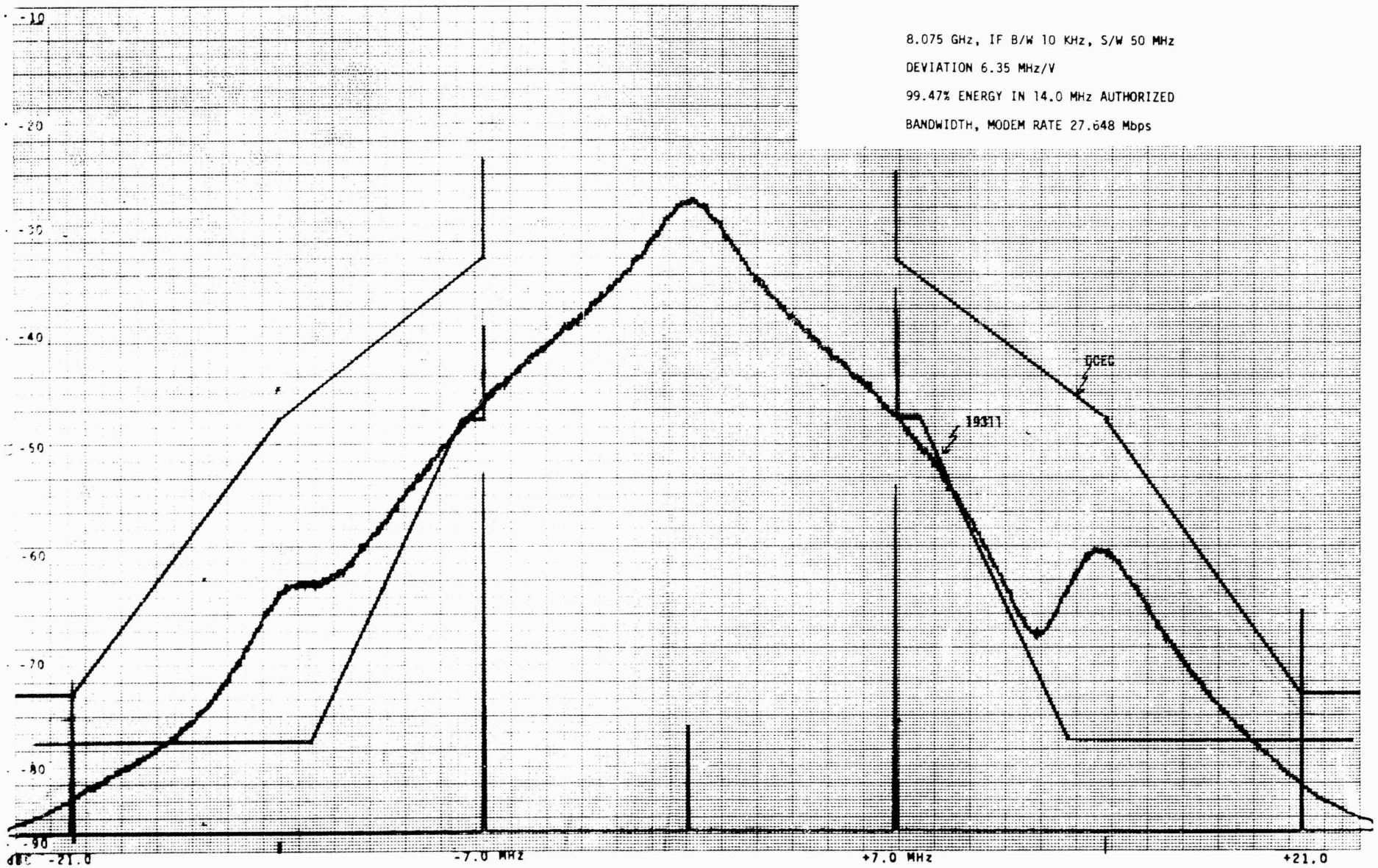

FIGURE 3: LC-8 D RF SPECTRUM, 2 X 12.672 Mbps, NORMAL RF FILTER

specification. In order to satisfy the FCC 19311 bandwidth specification spectral truncation of the transmitter output waveform is required. In performing this truncation care is required to minimize the error rate degradation due to the generation of intersymbol distortion components. A design goal of the program was to restrict the error rate performance degradation to 2 dB or less in the process of transforming the emission characteristics of the LC-8D radio set from a 99 percent to FCC 19311 constraint bandwidth. The approach was to design waveguide filters for the LC-8D radio which provided the necessary truncation, measure the IF to IF group delay characteristics of the LC-8D with the truncation filters installed, and based upon these measurements develop suitable receiver group delay equalizers.

3.3 Waveguide Filters

The normal waveguide filter for the LC-8D is a nominal 52 MHz (3 dB) filter. Consequently, this filter has little effect on the spectrum of a signal with 99 percent power within 14 MHz; a significantly narrower RF filter is required. Two waveguide filters were designed, built and tested. These were a 20 MHz (4 section) filter and a 15 MHz (5 section) filter which was subsequently opened up to 19 MHz.

3.3.1 20 MHz RF Filter Results

Figures 4 and 5 show the spectral results obtained with the 20 MHz filter for the 13.824 Mbps and 27.648 Mbps modem rates. These figures and all subsequent spectral curves were obtained using the same spectrum analyzer settings as given in Figures 2 and 3. At the lower rate the

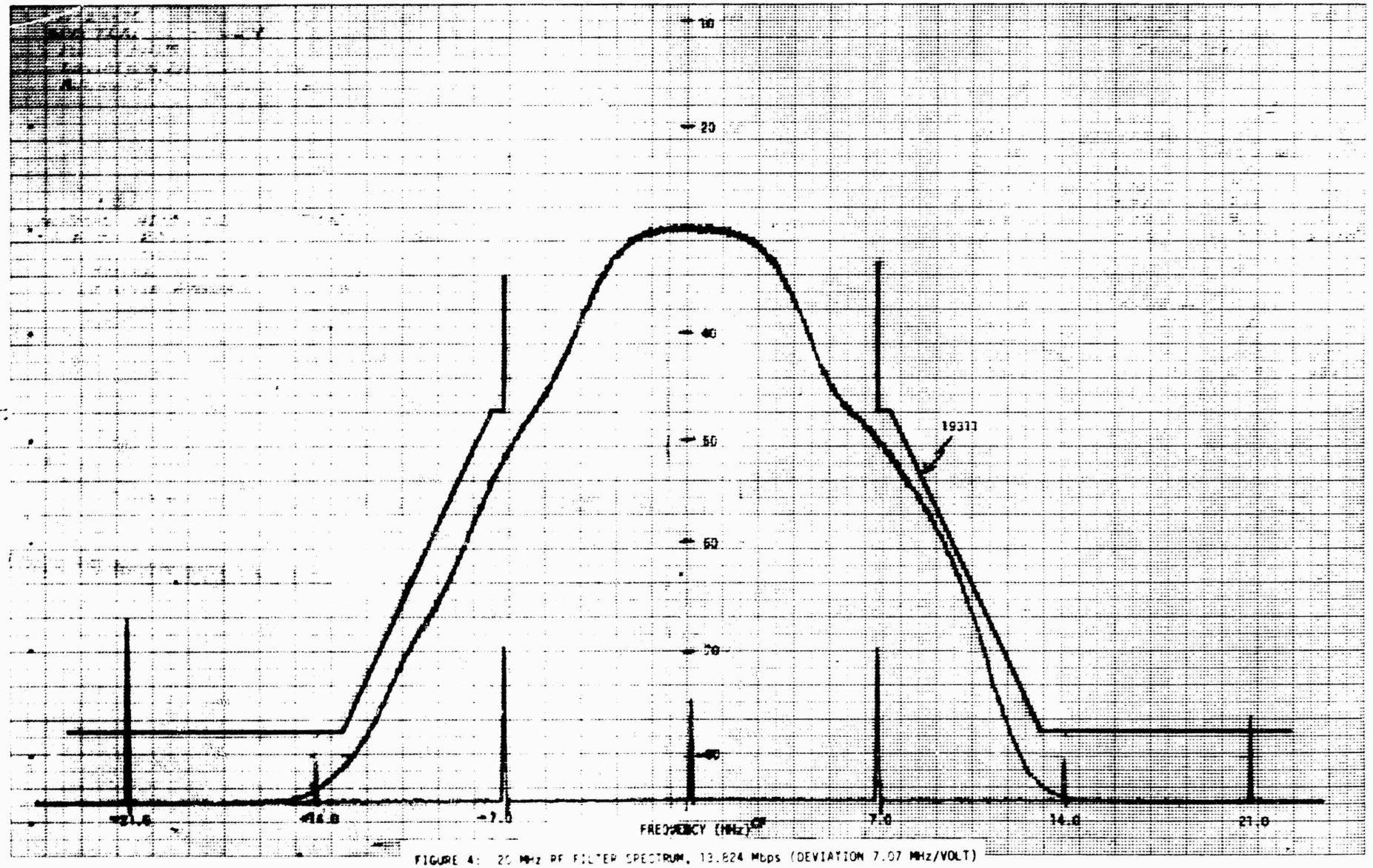

FIGURE 4: 20 MHz RF FILTER SPECTRUM, 13.824 Mbps (DEVIATION 7.07 MHz/VOLT)

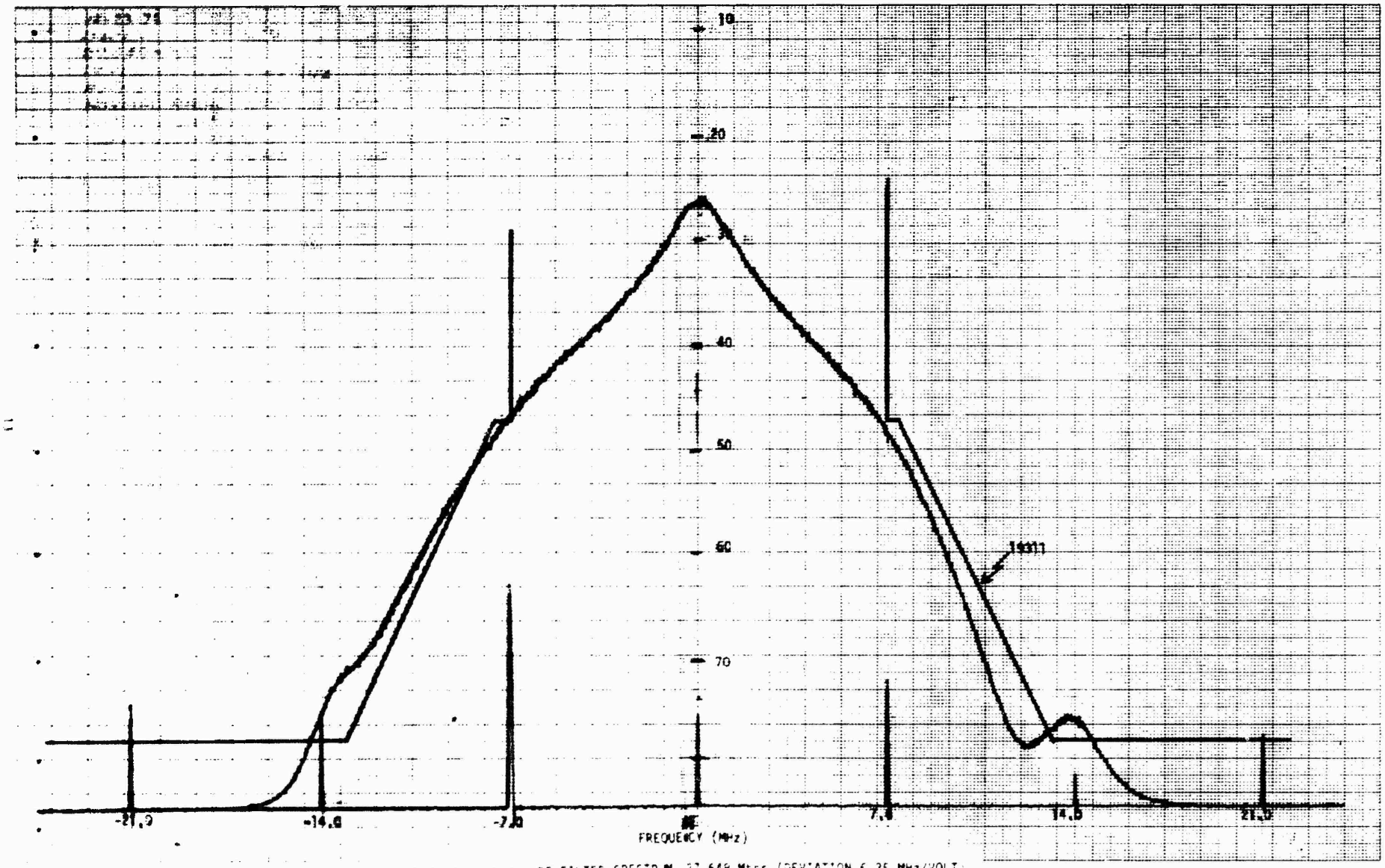

FIGURE 5 - 27 MHz RF FILTER SPECTRUM, 27.648 Mbps (DEVIATION 6.75 MHz/VOLT)

20 MHz filter has resulted in a sufficient amount of truncation while at the higher rate further truncation is required. Having established that the emission characteristics for the 13.824 Mbps meet the FCC Docket 19311 requirements, relative performance of the truncated and untruncated spectrums was measured. The results are shown in Figure 6. Prior to equalization truncation resulted in an approximate 1.5 dB performance degradation. However, by equalization the loss is recoverable. Consequently, for the 13.842 Mbps/14 MHz case, the 20 MHz filter, when utilized in conjunction with proper IF equalization, provides truncation sufficient to meet the docket requirements with little or no performance penalty.

3.3.2 15 MHz RF Filter Results

The spectral curve and FCC mask for the 15 MHz waveguide filter at the 27.648 Mbps rate is given in Figure 7. Note this figure obtained with a deviation of 6.35 MHz/volt quite readily satisfies the mask. The mask is also satisfied with this filter and a deviation setting of 10 MHz/volt. Thus, it is possible to use a higher deviation value than the 6.35 MHz/volt deviation originally used to satisfy the 99 percent bandwidth with the normal RF filter. Because of this possibility, the performance using this filter with different deviations was obtained and plotted as Figure 8. Performance using the normal LC-8D radio set's waveguide filter is also given for comparative purposes. These results indicate that at error rates of interest one would suffer a 3 to 4 dB performance degradation. Also demonstrated is the fact that some care

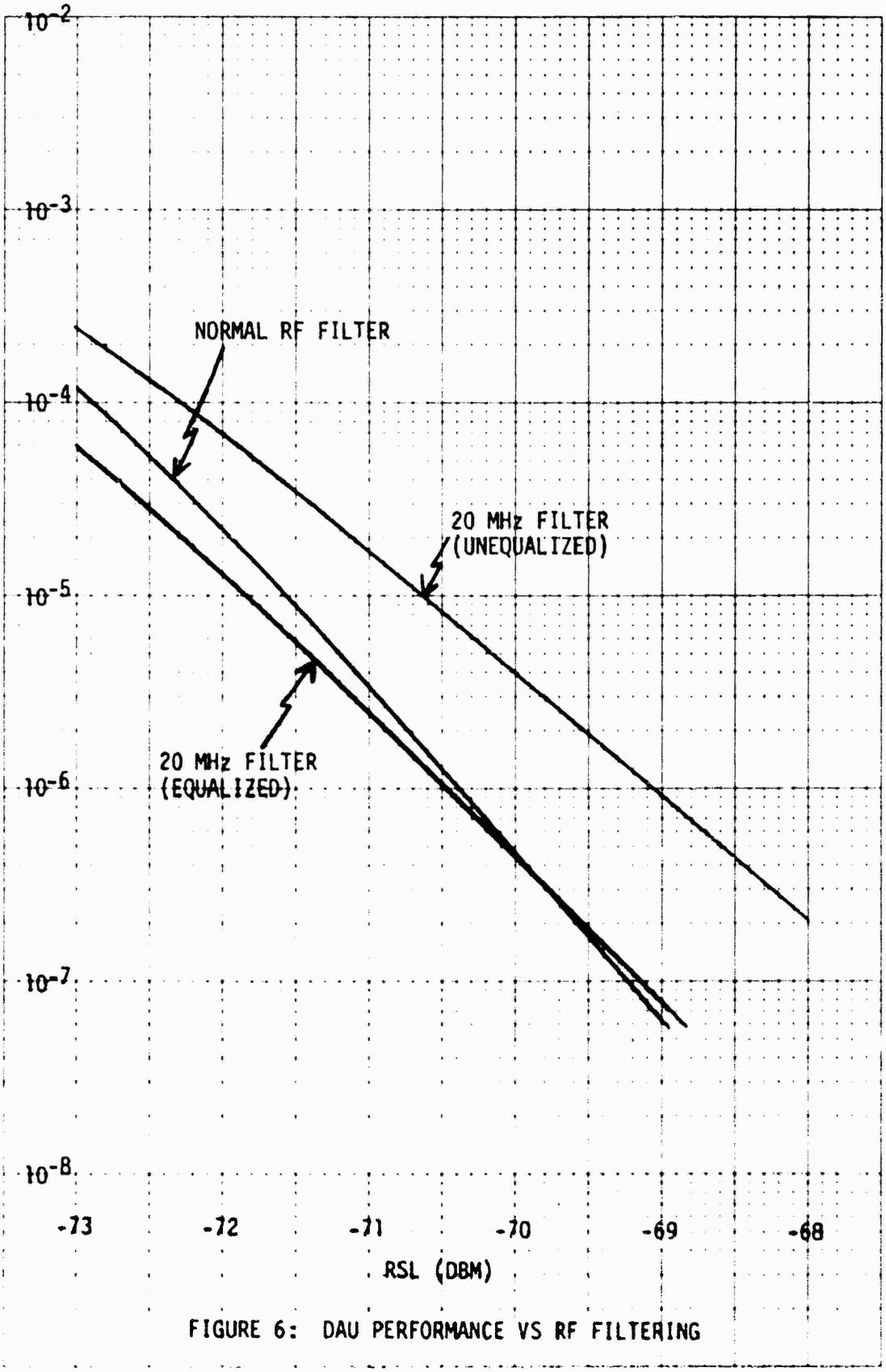

FIGURE 6: DAU PERFORMANCE VS RF FILTERING

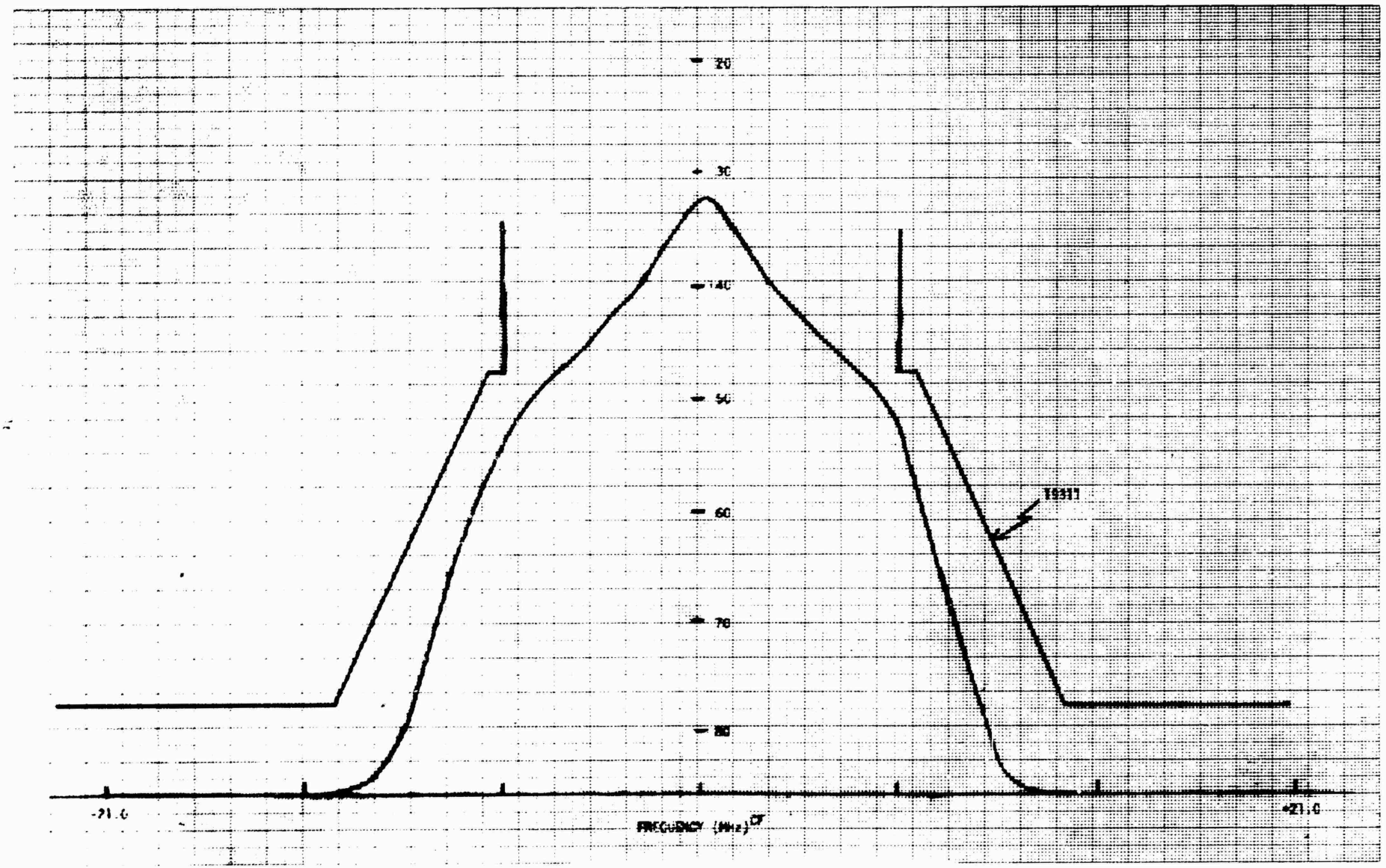

FIGURE [illegible] MHz RF FILTER SPECTRUM, 27.648 Mbps, DEVIATION 6.35 MHz/VOLT)

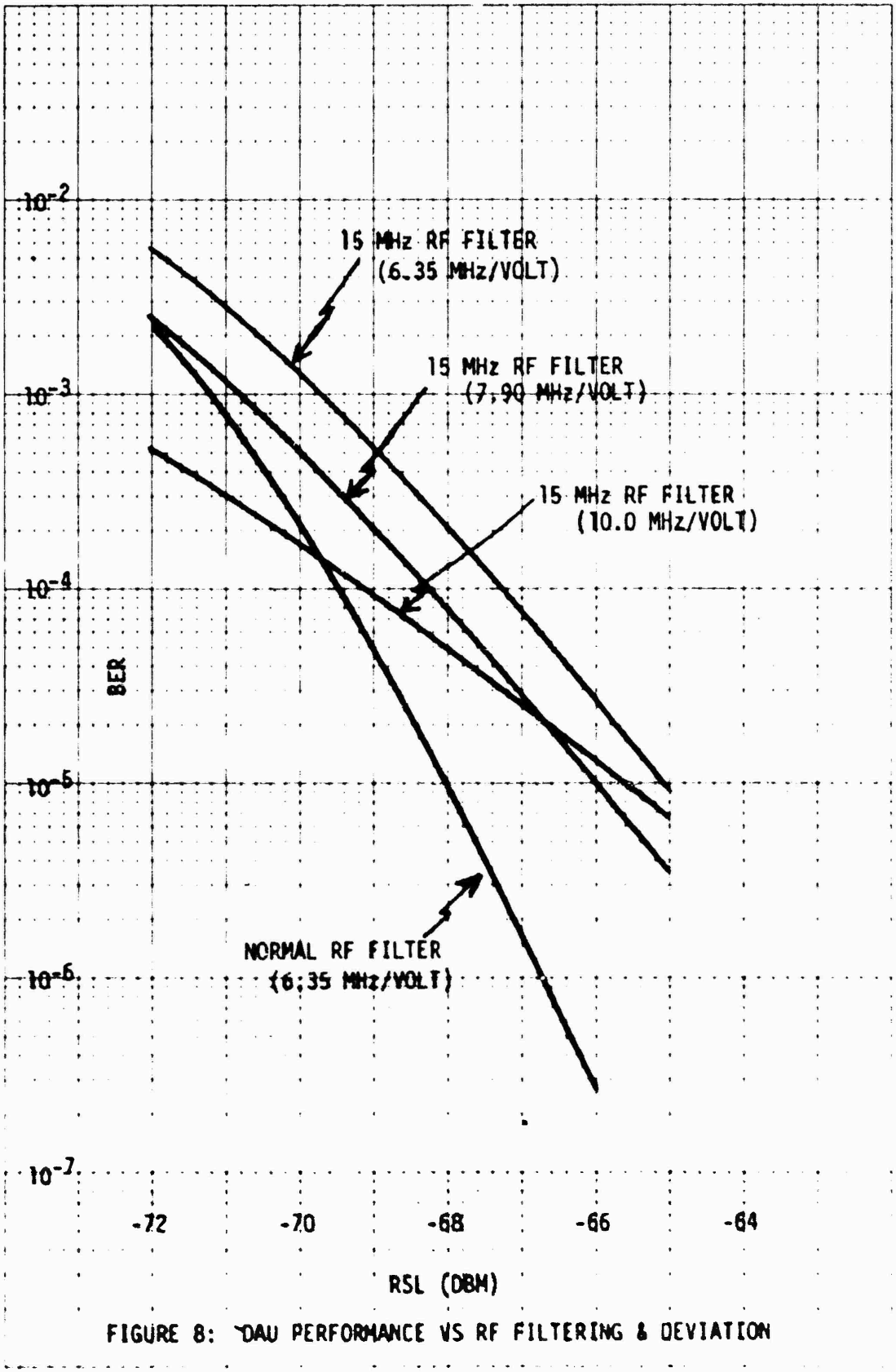

FIGURE 8: DAU PERFORMANCE VS RF FILTERING & DEVIATION

must be exercised in selecting deviation ratios so as not to over-deviate. Widening the deviation from 6.35 MHz/volt to 7.90 MHz/volt improved performance; increasing it to 10 MHz/volt flattened out the curve and resulted in a performance degradation for the stronger signal levels.

3.3.2.1 19 MHz RF Filter Results. The 5 section 15 MHz filter was opened up to ease the equalization and eliminate roll-off. The resulting spectral plot is shown in Figure 9. A marginal satisfaction of the mask is obtained. Figure 10 compares the performance obtained with the normal LC-8D RF filter and with the 19 MHz filter equalized to optimize performance. The difference is approximately 3/4 dB.

3.4 Conclusions with Respect to Filter Design

The spectrum in Figure 9 is very marginal with respect to satisfaction of the FCC Docket 19311 and, therefore, would be unacceptable for field use. Even if set up to with great care to satisfy requirements minor drifts in frequencies would shift the spectrum and cause a failure in meeting spectral requirements. The recommended approach towards satisfaction of FCC Docket 19311 would be to narrow the RF filter down from 19 MHz to 18 MHz and reduce the performance requirements of the DAU Specification by 1 dB. Suitable equalization networks would have to be provided to obtain such performance. At the lower data rate radio alignment is much simpler and no observable performance degradation occurred.

4.0 Cost Estimates

Based upon the necessary modifications indicated and the relative degree of alignment difficulty the contractor performed an analysis of the

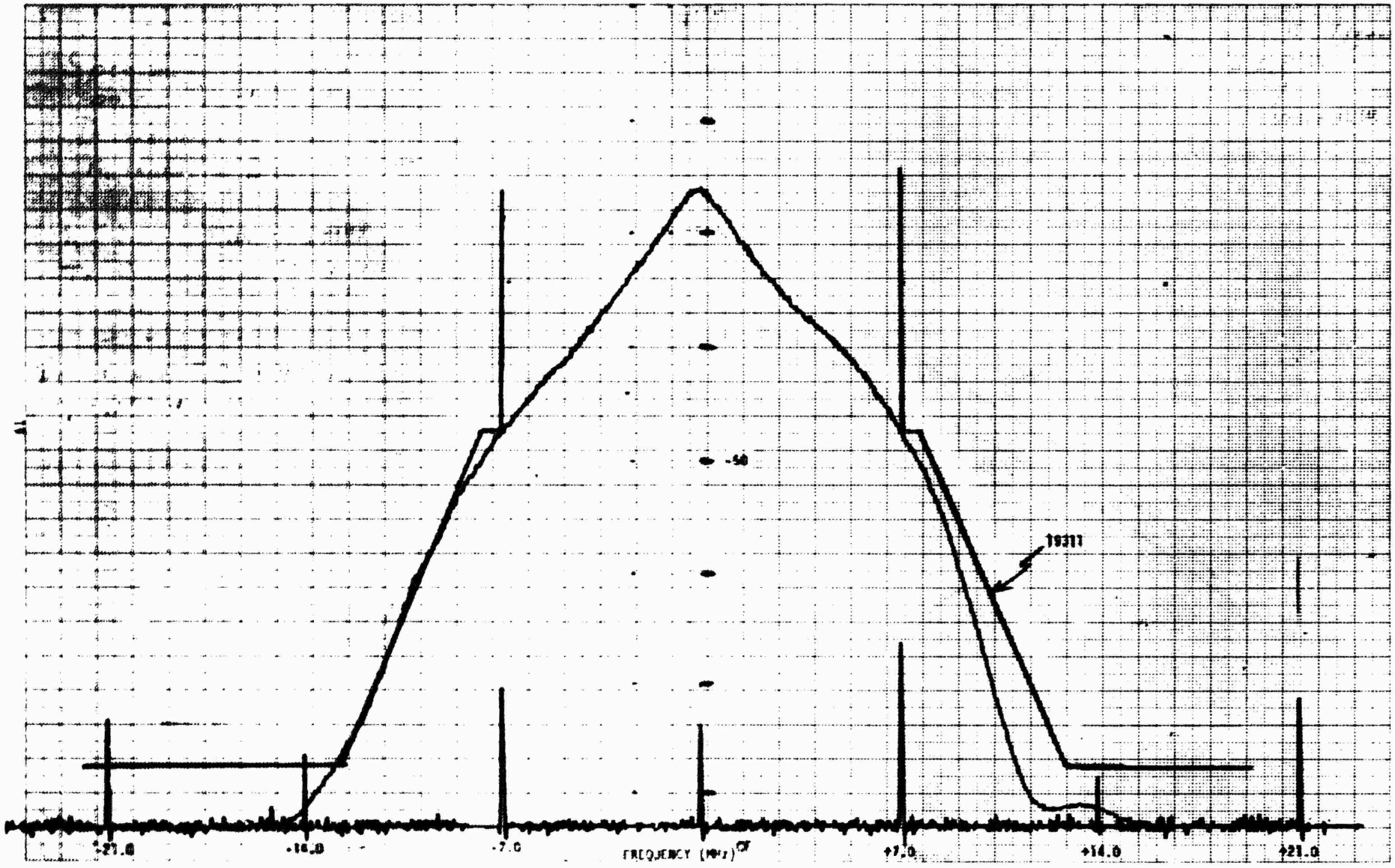

FIGURE 9: 15 MHz RF FILTER SPECTRUM, 27.648 Mbps (DEVIATION 6.35 MHz/VOLT)

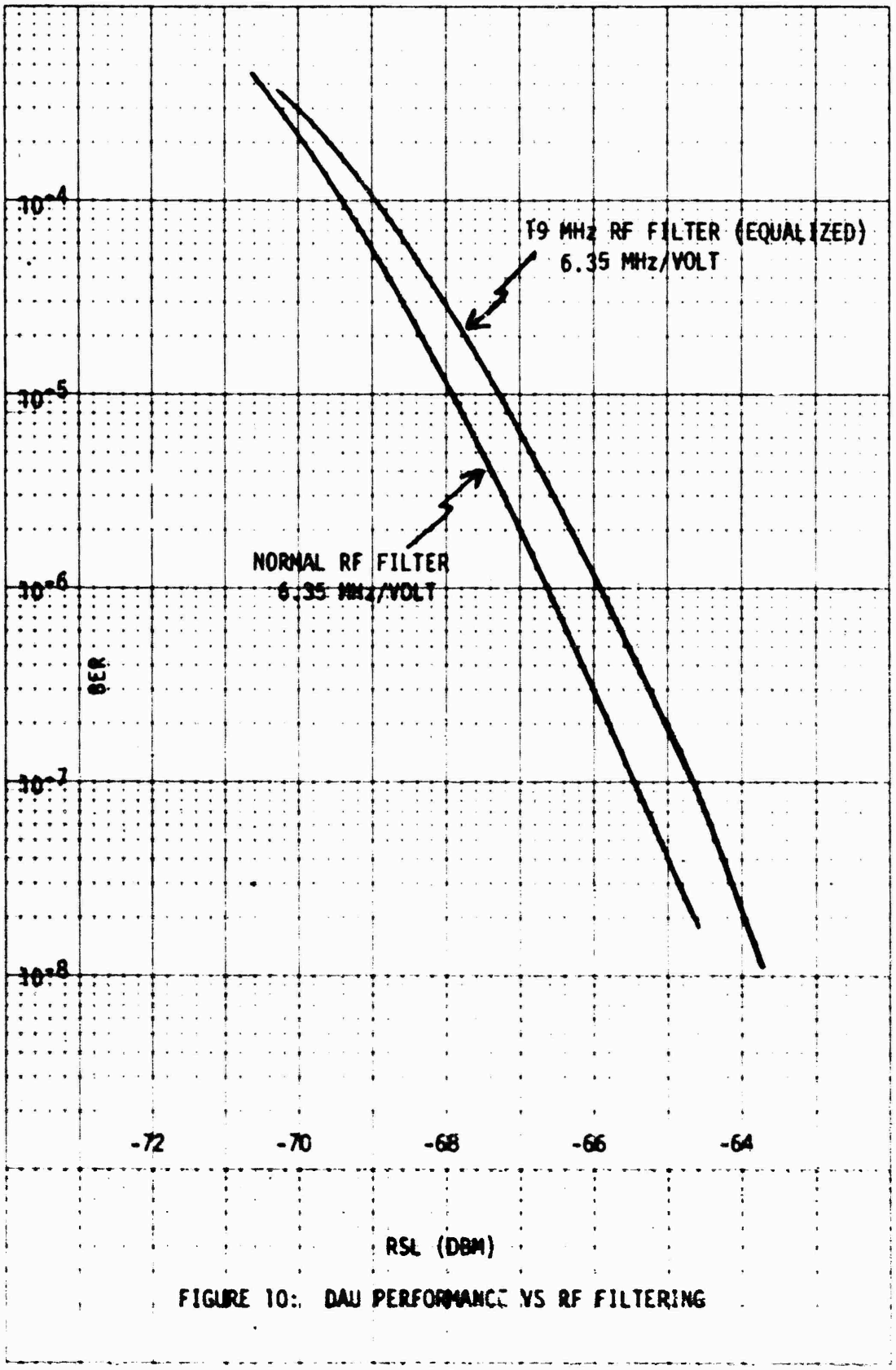

FIGURE 10: DAU PERFORMANCE VS RF FILTERING

costs that would be entailed in modifying 50 LCT terminals to satisfy the docket requirements. The estimated costs provided are given in Figure 11. Cost estimates average out to approximately $3,000 per radio.[1]

5.0 Modifications for Other Radios

While the above modifications were only effected for the LC-8D, the feasibility of changing other radio sets was investigated.

A study of the drawings for the 4 GHz LCT equipment indicates that a similar change can be made. The AN/FRC-162 DCS standard radio can also be modified in a similar fashion. However, since the length of the filter differs from that of the LCT radios, a different filter design would be required. Nevertheless, the modification difficulties and costs should be approximately equal.

The output filter used in the AN/FRC 80(V) equipment is a 2 section waveguide filter 2-1/2 inches long. To accommodate a filter providing the required out-of-band attenuation and passband insertion loss, the microwave section would have to be reconfigured. The 2-1/2 inch length does not allow sufficient clearance to insert two waveguide-to-coax-adapters which would permit an external filter to be added. One output filter per transmitter pair is employed which would require complete shutdown of the system during change-over. Alternate routing would be required. In order to generate a meaningful cost estimate each site would have to be addressed separately and far more detailed information obtained. The modification of this radio presents many more problems and as such would most likely entail higher costs.

1. Cost estimates based upon early 1977 rates.

ITEM 1:	SUPPORT COST		
	Cost to procure, expedite and kit material necessary to make modification		$12,907
	Cost to generate field modification bulletins		3,500
	Supervision		1,837
		Subtotal -	$18,244
ITEM 2:	COST TO MODIFY 50 LCT TERMINALS WHILE OPERATIONAL		
	Engineering and Supervisory Costs		$ 49,950
	Material		41,225
	Travel and Per Diem		34,666
		Subtotal -	$125,841
ITEM 3:	UPGRADE DOCUMENTATION		
	Modify engineering drawings, generate change pages and provide logistics data		$6,000
		Subtotal -	$6,000
		GRAND TOTAL -	$150,085

FIGURE 11: ESTIMATED COSTS FOR LCT TERMINAL UPGRADES

While the AN/FRC 80 is the only radio considered that would absolutely necessitate alternate routing, alternate routing seems to be the most practical method of effecting change-over for the other radio types as well.

6.0 Summary

The test results demonstrate that it is possible to modify the existing conventional FM radio sets in a manner that permits the satisfaction of FCC Docket 19311 when utilizing the DAU. Performance degradation caused by this restrictive bandwidth specification when compared with the other specifications can be kept to less than a dB. While the imposition of the FCC Docket 19311 requirement does not impose any severe technical difficulties, it would necessitate a rather significant cost penalty of about $3,000 per radio.

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3. "Spectrum Analysis Noise Measurements", Hewlett Packard Application Note 150-4, April, pp 7-11.

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